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Effect of brain magnetic resonance imaging on body core temperature in sedated infants and children

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Background. Children undergoing magnetic resonance imaging (MRI) under sedation are at risk of hypo- or hyperthermia. The effect of brain MRI at differing magnetic field strengths on body core temperature in sedated infants and young children has not been reported previously.

Methods. Two groups of 38 infants and children (aged 1 month to 6 yr 5 months) underwent brain MRI for different indications related to cerebral diseases, at 1.5 Tesla (T) and 3 T MRI units, respectively. All patients received deep sedation comprising midazolam, nalbuphine, and propofol. Pre-scan and post-scan temperatures were measured at the right tympanic and at rectal sites. No active warming devices were used during the procedures.

Results. Body core temperature measurements were similar between right tympanic and rectal site before and after the scans. After 1.5 T scans, the median (IQR) increase from pre-scan to post-scan tympanic temperature was 0.2°C (0.1–0.3), and the median (IQR) rectal temperature increase was 0.2°C (0–0.3) ($P<0.001$). After 3 T scans, the median (IQR) tympanic temperature increase was 0.5°C (0.4–0.7), and the median (IQR) rectal temperature increase was 0.5°C (0.3–0.6) ($P<0.001$).

Conclusions. Body core temperature increased significantly during 1.5 and 3 T examinations; this increase was more profound during 3 T MRI. Patient heating occurred despite minimal efforts to reduce passive heat loss under sedation and without the use of warming devices.

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Successful magnetic resonance imaging (MRI) requires the patient to stay still for up to 1 h or more in a noisy and claustrophobic environment. Infants and children may not lie still for long enough, so they require sedative drugs during the examination.[1] Sedation induces impairment of thermoregulatory control.[2 3] In addition, the MRI environment requires a cool ambient temperature for proper magnet function, which further predisposes infants and children to heat loss, so they may be at risk of hypothermia. Conversely, the MRI scanner generates radiofrequency radiation (RFR), which is absorbed by the patient. Even if clinically relevant warming of the body caused by RFR is unlikely during routine MRI in adults,[4 5] the large surface area–body weight ratio of children may potentially result in an increase in body temperature.[6 7]

We designed this study to investigate the effect of absorbed RFR during brain MRI on the body core temperature of sedated infants and children. We hypothesized that the body core temperature of infants and children would increase during MRI examinations and that core temperature would increase more in 3 Tesla (T) than in 1.5 T MRI systems.

Methods

Patients

After IRB approval, 76 consecutive ASA I–II infants and children who required sedation for elective cranial MRI examinations were enrolled in this prospective study. Informed consent was obtained from the parents of all patients. Exclusion criteria were ASA status ≥III, severe pulmonary or cardiovascular disease, anatomic airway abnormalities which may interfere with deep sedation

under spontaneous respiration, body core temperature $\geq$37.5°C at baseline, and the primary requirement for general anaesthesia with tracheal intubation for MRI examination. Children with cognitive impairment or developmental delay were not excluded. Two groups were investigated: those who were scanned using 1.5 T were compared with those scanned using 3 T. Patients were allocated to the respective MRI scanner by the paediatric neuroradiologist according to the clinical indication and patient's suitability for a high-field-strength examination.

Procedure

On the day of the procedure, all patients were admitted to the paediatric day care ward and an i.v. cannula was inserted. All patients wore the same kind of cotton pyjamas, delivered by the paediatric ward. In the MRI induction room, patients were pre-medicated with i.v. midazolam 0.1 mg kg^{-1}. Sedation was induced with i.v. nalbuphine 0.1 mg kg^{-1} and followed by a loading dose of propofol 1 mg kg^{-1}. Supplemental doses of propofol 0.5 mg kg^{-1} were administered until adequate sedation was achieved.[8]

Pre-scan rectal (Thermoval Classic, Paul Hartmann AG, Germany) and pre-scan tympanic temperature (FirstTemp Genius 3000 A, Sherwood Medical, St Louis, USA) were then recorded.[9–11] The right ear was chosen for tympanic temperature measurement in all patients.

Patients were then moved into the MRI suite, and ambient temperature was measured (TK-5110, ATP Messtechnik, Germany). Earplugs were placed in both ears. Sedation was maintained with propofol 5 mg kg^{-1} h^{-1} and supplemental oxygen was delivered by paediatric facemask with a gas flow rate of 2 litre min^{-1}. Heart rate, peripheral oxygen saturation (Sp_{O_2}), and end-tidal carbon dioxide ($P_{E'CO_2}$) were monitored continuously during the procedure. Non-invasive arterial pressure was determined immediately before the induction of sedation and at the end of the examination. The MRI scanner used was a 1.5 T Philips Intera (Philips, Medizinische Systeme GmbH, Austria) or a 3 T Magnetom Trio Tim (Siemens AG, Medizintechnik, Austria) with quadrate (transmit and receive), so-called 'head matrix' head coils. Brain sequences represented normal protocols used for infants and children at our institution and required contrast application with dotarem (Gd DOTA) 0.2 mg kg^{-1}. The number and the duration of the sequences and the specific absorption rate (SAR) values for each sequence were recorded.

After the MRI examination was completed, the propofol infusion was terminated and the patient transferred from the MRI suite to the induction room. Earplugs were then removed, and post-scan rectal and post-scan tympanic temperatures were recorded. Temperature measurements were performed by the same investigator in all patients.

In addition, sweating was evaluated qualitatively: a sweating grade of 0 was assigned when no moisture was detected, a grade of 1 when some moisture was detected, and a grade of 2 when distinct beads of sweat were visible, independent of the localization.[12]

Data analysis

Groups were descriptively compared for balance on baseline potential confounding variables using standard summary statistics. Data are presented as median (IQR) or mean (SD) depending on their distribution. Normal distribution was assessed with q–q plot and Shapiro-Wilk test. Normally distributed data were analysed with two-sided unpaired Student's *t*-test; Mann-Whitney *U*-test or Wilcoxon signed ranks test was used for data sets which diverged from the normal distribution. Categorical data were analysed using Fisher's exact test. Bland–Altman analysis was performed to calculate the differences between tympanic and rectal temperatures obtained at pre-scan and post-scan assessment. The distribution of the differences was plotted against the means of both measurement sites. A *P*-value of 0.05 was considered significant. Analyses were conducted using SPSS software (SPSS Inc., Chicago, IL, USA, Version 12.0.1).

Sample size consideration

The single similar study reported that mean tympanic temperatures in older children increased 0.5°C after 1.5 T MRI of the brain.[6] We assumed a difference of 0.5°C between the two groups (1.5 and 3 T) as clinically important. Power analysis indicated that 26 patients in each group would provide a 95% chance of identifying a statistically significant difference between the groups at a two-tailed alpha level of 0.05. We therefore planned to study a minimum of 52 patients.

Results

We approached 80 consecutive infants and children (aged 1 month to 6 yr 5 months) who underwent elective MRI examinations of the brain during a 3 month period (July 2008–September 2008). During this period, four patients were excluded because body core temperature was $\geq$37.5°C at baseline. Data were obtained from the remaining 76 patients. Patients were classified as ASA grade I (48% of patients) or ASA II (52%). The indications for MRI were epilepsy (22 patients), cerebral tumour staging (47 patients), investigation for retardation (6), and investigation for autism (1). Patients were divided into two groups, depending on in which MRI scanner the examination was performed: group 1.5 T and group 3 T (Table 1).

All scheduled MRI examinations were completed without any failure of sedation. No patient moved during

the examination, so no additional sedative medication was required. No patient suffered from adverse respiratory or cardiovascular events and no paradoxical reactions to sedation or agitation were seen. MRI examination protocols of the 1.5 and 3 T scanner were comparable regarding the type of sequences and the SAR values, but the total duration of the procedure was significantly longer in 3 T examinations (Table 1). SAR values ranged from 0.3 to 3.9 W kg^{-1} (watts per kilogram) depending on the sequence performed, but did not exceed 4 W kg^{-1} over 15 min. The ambient temperature of the MRI suite lay between 20°C and 22°C during all examinations.

Body core temperature measurements correlated well between tympanic and rectal sites. Ninety-five per cent of the differences between pre-scan tympanic and rectal temperatures were between −0.43°C and 0.47°C (Fig. 1A). Similarly, 95% of the differences between post-scan tympanic and rectal temperatures were between −0.35°C and 0.49°C (Fig. 1B). A bias of 0.02°C (pre-scan) and 0.07°C (post-scan) demonstrates that tympanic temperature accurately reflected rectal temperature measurements. Absolute post-scan temperatures were significantly higher compared with pre-scan temperatures at both measurement sites but differences were greater after 3 T MRI than 1.5 T MRI (Table 2). Tympanic and rectal temperatures increased in 35 of 38 patients (92%) and remained unchanged in three patients (8%) after 1.5 T MRI examinations. The MRI scan times were 31–34 min in these patients. Accordingly, tympanic and rectal temperatures increased in 37 of 38 patients (97%) and remained unchanged in one patient (3%) after 3 T MRI examination with a scan time of 36 min. We did not measure a decrease of body temperature in any patient.

Two patients had temperature increases up to 0.9°C after 1.5 T examination times of 33 and 38 min, whereas three patients had temperature increases up to 1°C after 3 T examination times between 31 and 42 min. All patients sweated after the examination: a sweating grade of 1 was documented in 27 of 38 (71%) patients after 1.5 T MRI, and in 22 patients (58%) after 3 T MRI. Thus, a sweating grade of 2 was seen in the remaining 11 patients (29%) after 1.5 T MRI, and in 16 patients (42%) after 3 T MRI.

Table 1 Patient data. Values are median (IQR) or number. MRI scan times are mean (SD). *P=0.037, Fisher's exact test

	Group 1.5 T	Group 3 T
Number of patients	38	38
Age (yr)	3.9 (1.4–4.5)	3.8 (2.3–4.4)
Weight (kg)	15.1 (11.5–18.9)	16 (12.5–18.4)
Height (cm)	97.5 (63.8–107.1)	98.5 (85.8–106.3)
BMI (kg m^{-2})	15.8 (14.7–17.3)	16.2 (15.3–17.8)
Gender (m/f)	20/18	16/22
MRI scan time (min)	31.1 (7.7)	35.4* (10)

Discussion

To our knowledge, this is the first study dealing with the effect of 3 T MRI on body core temperature in infants and children. Core temperature increased significantly during 1.5 and 3 T examinations and the post-scan temperatures were significantly greater after 3 T MRI than 1.5 T MRI. Core temperature increased despite no active warming devices being used during MRI, and the ambient temperature of the MRI suite being maintained at 20–22°C. Two patients had temperature increases up to 0.9°C after 1.5 T MRI, and three patients had increases up to 1°C after 3 T MRI. The majority of patients were sweating after the examination. We also observed that body core temperature

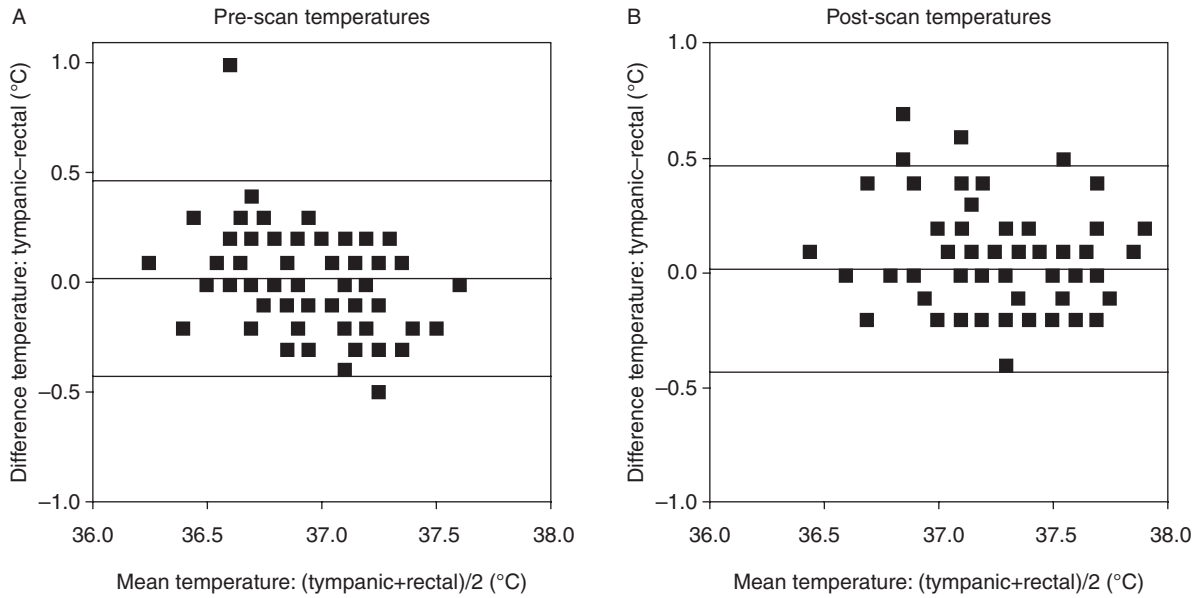

Fig 1 (A) Bland–Altman plot of differences against means of pre-scan tympanic and rectal temperatures. (B) Bland–Altman plot of differences against means of post-scan tympanic and rectal temperatures.

Table 2 Absolute temperatures presented as median (IQR). *$P<0.001$ compared with pre-scan (Wilcoxon signed ranks test). †$P<0.001$ compared with Group 1.5 T (Mann–Whitney test)

	Pre-scan	Post-scan
Group 1.5 T		
Tympanic temperature (°C)	37 (36.8–37.1)	37.2* (37.1–37.3)
Rectal temperature (°C)	36.9 (36.6–37.2)	37.1* (36.9–37.5)
Group 3 T		
Tympanic temperature (°C)	37 (36.7–37.1)	37.5*,† (37.3–37.7)
Rectal temperature (°C)	37 (36.7–37.1)	37.5*,† (37.2–37.6)

measurements correlated well between tympanic and rectal sites, both at pre-scan and post-scan assessments.

It is known that sedated children have the tendency to develop hypothermia triggered by anaesthesia-induced impairment of thermoregulatory responses more rapidly than adults because of their large surface area-to-body weight ratio.[2 3] The thermoregulatory effects of the drugs administered with our sedation regimen have been investigated in adults[8 13–16] and if we assume that these effects are more profound in children, hypothermia would be anticipated. In addition, the MRI environment requires a cool ambient temperature for proper magnet function, which further predisposes children to heat loss. However, the MRI scanner generates RFR, which is absorbed by the patient. The quantity of RFR absorbed during MRI examinations is described as the SAR (W kg^{-1}) and defined as the 'time derivate of incremental energy absorbed by and in turn dissipated in an incremental mass contained in a volume element of given density'.[6 17] International guidelines limit SAR values to a whole-body average of 4 W kg^{-1} body weight over 15 min.[6 18 19] These guidelines were developed for awake adults and may not be applied to the sedated child in whom thermoregulation might be impaired. Sedated children may therefore be at increased possibility for clinically significant radiofrequency absorption and clinically relevant heating.

For more than a decade, a magnetic field strength of 1.5 T has been the reference standard for clinical MR systems and has been used for virtually all MR applications. The rationale for imaging at higher field strength is that the resolution of various anatomic structures in 3 T MRI appears to be superior to that of 1.5 T MRI. However, the global examination time on the 3 T unit may be longer because the SAR of 3 T MRI is markedly greater than that of 1.5 T MRI.[20] Thus some resting periods between the sequences have to be considered. Therefore, the heating of tissue by the absorbed radiation may be a critical factor for 3 T MR system more than for 1.5 T MR system.

Until now, only one study has investigated adult volunteers in 3 T MRI and documented an increase of body temperature of 0.46 (SD 0.12)°C after brain examinations.[21] That increase was regarded as safe concerning the thermoregulatory stress. Bryan and colleagues[6] documented a mean increase of tympanic temperature of 0.5°C after 1.5 T MRI examinations of the brain in young children (mean age 14.9 months). Patients were sedated with chloral hydrate, a regimen which resulted in a lower sedation level but perhaps more thermoregulatory impairment than our propofol-based regimen. In addition, one case report documented accidental hyperthermia (38°C) after cardiac MRI in a young girl. The depth of sedation may influence the degree of thermoregulatory impairment, even if not demonstrated in children until now. Our patients were not anaesthetized completely, and most of them showed residual intrinsic thermoregulatory responses consistent with heating: almost all of our patients sweated profusely. This may be additionally explained by the fact that propofol only slightly alters the sweating threshold.[15 16]

We chose to measure tympanic temperature, because measurement is fast and correlates closely with body core temperature.[11 22] Because infrared ear thermometry did not show sufficient agreement with the established method of rectal temperature measurement in a review of 5935 children,[10] we measured rectal temperature simultaneously. In addition, the values of both measurement sites and their good correlation allow us to exclude the possibility of preferential RFR absorption by the head, resulting in differential heating of the head relative to the rest of the body.[6]

If we assume that the body temperature increases in our patients were caused by MRI scanner deposition of RFR, then SAR values and examination times calculated by the manufacturers of 3 T MRI systems should be revised to prevent hyperthermia of infants and small children. Unintentional heating seems to be an under-appreciated risk especially of high-field-strength MRI, and clinicians should consider the possibility of body temperature increases. MRI-safe, reliable, and economical instruments for continuous temperature monitoring are desirable, especially for fevered, critically ill, or compromised infants and children.

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